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RESEARCH

Nitrogen Extraction by Cotton Fertilized with Broiler Litter

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ABSTRACT

Inefficient extraction of litter-derived N and its loss to the immediate environment is a concern when poultry litter is used as a fertilizer. This research determined the magnitude of N extraction by cotton (*Gossypium hirsutum* L.) fertilized with broiler litter with or without supplemental inorganic N. Extraction of N by cotton fertilized with litter rates of 2.2, 4.5, and 6.7 Mg ha^{-1} in combination with 0, 34, or 67 kg ha^{-1} N as urea–ammonium nitrate (UAN) was determined on two farms, one at Cruger and another at Coffeeville, MS, in 2002 to 2004. The treatment that received 4.5 Mg ha^{-1} litter plus 67 kg ha^{-1} UAN-N was among the treatments that had the largest N extraction with an average across years of 233 kg N ha^{-1} total extraction at Cruger and 183 kg N ha^{-1} at Coffeeville. These extractions were more or only slightly less than the total applied N. An average of 56% of extracted N at Cruger and 62% at Coffeeville was partitioned to seed and lint, which represents an amount that would be removed from the field. The remainder is bound in plant parts with little or no risk of becoming released to the immediate environment until the plant parts decompose. These results demonstrate cotton is efficient at extracting N supplied by as much litter as 6.7 Mg ha^{-1} when supplemented with inorganic N. The risk of N detrimentally affecting the immediate environment when cotton is fertilized with litter plus inorganic N is no greater than when fertilized with 100% inorganic N fertilizers.

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Abbreviations: DAP, days after planting; NEE, nitrogen extraction efficiency; N_{TPA}, applied total plant available nitrogen; STD, farm standard fertilization; UAN, urea–ammonium nitrate.

Nitrogen fertilization of cotton (*Gossypium hirsutum* L.) with poultry litter is difficult to manage because litter-N exists in both organic and inorganic forms. The inorganic fraction, usually in the ammonium (NH_4^+) form, may constitute 10 to 60% of the total litter-N (Collins et al., 1999; Chadwick et al., 2000). This mineral N fraction is readily available for plant absorption either as NH_4^+ or after conversion to NO_3^- by nitrification processes in the soil. The plant uptake characteristic of the mineral fraction of litter N should, therefore, parallel that of conventional fertilizers such as ammonium nitrate and urea–ammonium nitrate (UAN) solution. The organic fraction of litter N is found in the form of proteins, nucleic acids, and other organic compounds derived from plant or animal tissues. This fraction of the litter-N, which may constitute 40 to 90% of the total litter N (Collins et al., 1999; Chadwick et al., 2000), becomes plant available only after mineralization via soil microbial activity. At the time of land application, it is difficult to predict how much of the N from the organic fraction will be available for plant uptake and utilization during the growing season.

Loss of litter-derived organic and inorganic N to the immediate environment due to inefficient extraction is a concern when

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poultry litter is used as a primary row crop fertilizer. A few empirical studies, mostly on forage and pasture grasses, have documented the magnitude of extraction and utilization of litter-derived N. Evers (2002), for example, determined N uptake in a pasture of annual ryegrass (*Lolium multiflorum* L.) and bermudagrass [*Cynodon dactylon* (L.) Pers.] fertilized with broiler litter with supplemental commercial N fertilizer. He reported a maximum annual N uptake of 285 kg ha^{-1} when the ryegrass–bermudagrass pasture was fertilized with 341 kg N ha^{-1} from litter plus 224 kg N ha^{-1} from NH_4NO_3 applied four times during the year. The N uptake was only 84 kg ha^{-1} by ryegrass and 69 kg ha^{-1} by bermudagrass for a total of 153 kg ha^{-1} annual N uptake when litter was the only source of applied N. This uptake represented 45% of the total litter-supplied N. Using container experiments, Chadwick et al. (2000) estimated the total uptake of organic litter-N by perennial ryegrass (*L. perenne* L.) to range between 16 and 56%, and reported even less uptake of organic N derived from dairy and pig slurries. Brink et al. (2004) measured N uptake by common and six hybrid bermudagrass cultivars fertilized with 11.8 Mg ha^{-1} yr^{-1} dry litter that supplied 540 kg total N ha^{-1} yr^{-1}. Total N uptake when averaged across the cultivars and 4 yr was 316 kg ha^{-1} on an annual basis, which represents 58% of the total applied litter-N.

Uptake and utilization of litter-derived N by cotton, unlike forage and pasture grasses, is not researched or is not well documented. Past studies on N uptake by cotton pertain to commercial fertilizers that may serve as a guide on the capacity of cotton to extract N from the soil. Maximum uptake of 235 kg ha^{-1} was reported by Halevy (1976) from research conducted in Israel where two cultivars (Acala 1517-C and Acala 4–42) were grown with irrigation and fertilized with 100 kg ha^{-1} inorganic N. Other reports show uptake much less than 235 kg ha^{-1}. Bassett et al. (1970) used Acala 4–42 under irrigation in California and reported ≈38% less total N uptake (142 kg N ha^{-1}) although they applied 34% more N than Halevy (1976). Mullins and Burmester (1990) reported even less average N uptake (128 kg ha^{-1}) by four cultivars fertilized with 78 kg ha^{-1} N in the southeastern U.S. cotton production region. Boquet and Breitenbeck (2000) reported an uptake of 160 kg ha^{-1} N by mature cotton that received 84 kg N ha^{-1}, which supported normal cotton production in the southeastern USA. When they applied twice (168 kg ha^{-1}) as much N, the N in aboveground plant parts increased only slightly to 179 kg ha^{-1}. Olson and Bledsoe (1942), who also conducted their research in the southeastern U.S. cotton production region >60 yr ago, reported an uptake of 94 to 151 kg ha^{-1} N (depending on the soil type) by aboveground plant parts of cotton fertilized with only 40 kg ha^{-1} N. These reports suggest the capacity of cotton to extract N from the soil probably depends on the cultivar, soil type, and other conditions that affect plant growth.

The objective of this research was to determine the magnitude and efficiency of N extraction and utilization by cotton fertilized with broiler litter with or without supplemental inorganic N fertilization. The research was part of a larger program with an overall goal of developing management methods and prescriptions for using poultry litter as a primary fertilizer for cotton in the southeastern USA. Lint yield and fiber quality results are presented elsewhere (Tewolde et al., 2007).

MATERIALS AND METHODS

The research was conducted on two commercial farms representing conventional-till at Cruger (33°18'20" N, 90°14'39" W, 32.9 m altitude) and no-till at Coffeeville (33°58'12" N, 89°41'9" W, 71.2 m altitude), MS, in 2002, 2003, and 2004. The soil at Cruger was a Dubbs silt loam (fine-silty, mixed, active, thermic Typic Hapludalf) and the soil at Coffeeville was an Ariel silt loam (Coarse-silty, mixed, thermic Fluventic Dystrochrepts). Cotton was grown continuously on the same soil for >25 yr at Cruger and for 4 yr at Coffeeville before initiating this research. At each location, total amount and efficiency of N extraction by cotton fertilized with fresh broiler litter rates of 2.2, 4.5, and 6.7 Mg ha^{-1} in an incomplete-factorial combination with 0, 34, or 67 kg ha^{-1} N side-dressed as UAN was determined. The combinations included $L_{2.2}N_0$, $L_{2.2}N_{34}$, $L_{2.2}N_{67}$, $L_{4.5}N_0$, $L_{4.5}N_{34}$, $L_{4.5}N_{67}$, $L_{6.7}N_0$, and $L_{6.7}N_{34}$ where L = litter, N = nitrogen as UAN and a subscript represents litter (Mg ha^{-1}) or N (kg ha^{-1}) rate. The supplemental UAN-N rates in 2004 at Cruger were 0, 67, and 135 kg N ha^{-1}. Extraction from an unfertilized control (L_0N_0) and a farm standard fertilization (STD) were included to make a total of 10 treatments.

The 10 treatment combinations within each location were tested in a randomized complete block design with three or four replications. The plots consisted of four 119-m-long rows spaced 1.02 m apart at Cruger and eight 73-m-long rows spaced 0.97 m apart at Coffeeville. Each treatment was applied to the same plot in all 3 yr. Each year, UAN solution (32% N) was applied between square and first flower stage as a sidedress using a commercial liquid fertilizer applicator equipped with coulters that opened slits about 0.15 to 0.20 m away from the row center into which the UAN solution was injected to a depth of ≈0.1 m. Nitrogen, P, and K fertilizers were applied to the STD at the same rate as adjacent fields as practiced by the respective farm. This treatment received 135 kg N ha^{-1} as UAN each of the 3 yr at Cruger. At Coffeeville, the treatment received 101 kg N ha^{-1} in 2002 and 118 kg N ha^{-1} in 2003 and 2004 as UAN. Phosphorus was applied as triple superphosphate (0–46–0 N–P_2O_5–K_2O) to the STD at 0, 20, and 0 kg P ha^{-1} at Cruger and 29, 20, and 0 kg P ha^{-1} at Coffeeville in 2002, 2003, and 2004, respectively. Potassium was applied to the STD as KCl (0–0–60 N–P_2O_5–K_2O) at 140, 98, and 93 kg K ha^{-1} at Cruger and 56, 75, and 112 kg K ha^{-1} at Coffeeville in 2002, 2003, and 2004, respectively. All P and K fertilizers were applied to the STD as a broadcast by hand before planting.

Litter was applied 3, 1, and 10 d before planting at Cruger in 2002, 2003, and 2004, respectively. At Coffeeville, litter was applied 22 d before planting in 2002, 25 d after planting (DAP) in 2003, and 9 DAP in 2004. Each year, the litter was broadcast applied with a commercial fertilizer spreader equipped with ground speed–sensing radar, an electronic scale, and a rate-control computer system (Barrons & Brothers, Inc., Gainsville, GA). Litter was soil incorporated in the same day of application under the conventional-till at Cruger and was not incorporated under no-till at Coffeeville. Cotton was planted on 19 Apr. 2002, 16 Apr. 2003, and 19 Apr. 2004 at Cruger and on 21 May 2002, 2 May 2003, and 28 Apr. 2004 at Coffeeville. Additional details on crop management, weather, and litter chemical properties are provided elsewhere (Tewolde et al., 2007).

Nitrogen extraction was determined based on aboveground whole plant samples collected from 0.5 to 0.6 m^2 in the center rows of each plot. Plant samples were taken four times during the 2002 and 2003 growing seasons from Cruger and during the 2002 growing season from Coffeeville. The samples from Cruger were taken 68, 97, 112, and 130 DAP in 2002 and 78, 98, 121, and 135 DAP in 2003. The samples from Coffeeville were taken 50, 71, 93, and 112 DAP in 2002. In other years, plants were sampled only at the end of the season 134 DAP in 2004 from Cruger and 137 DAP in 2003 and 138 DAP in 2004 from Coffeeville. Each year, cotton started flowering in late June at Cruger and in early to mid-July at Coffeeville.

Plants sampled were cut at soil level, separated by hand into leaves (leaf blade + petioles), stems (branches + main stem), and reproductive parts (squares + flowers + bolls). Plant parts were dried in a forced-air oven at 80°C to constant weight, weighed, and ground to pass a 1-mm sieve. Reproductive parts were further separated into burs, seed, and lint after drying when bolls were mature enough to make the separation feasible. Lint was separated from seed using a 10-saw gin. Seed samples were delinted with H_2SO_4 before grinding, as linters on seed made homogenization extremely difficult.

Total N concentration in the different plant parts was determined by an automated dry combustion method using a ThermoQuest (CE Elantec, Inc., Lakewood, NJ) C/N analyzer (Horneck and Miller, 1998). Accumulation of N in each plant part was calculated as the product of N concentration and dry weight of each plant part. Total N accumulated by aboveground plant parts was determined as the sum of N accumulated in leaves, stems, and reproductive parts. Lint N concentration was not analyzed on all samples as the N content of lint is known to be low (≈2.5 g kg^{-1} around maturity) and varies little with N nutrition (Fritschi et al., 2004). Only the 2002 lint samples from Cruger were analyzed for N after thoroughly cleaning each sample by hand to remove visible debris. The lint N concentration of these samples was used to determine total lint N accumulation in all years at both locations. The efficiency of cotton to extract applied N, which is sometimes referred to as apparent N recovery (Scholberg et al., 2000), was evaluated by computing extracted N as a percentage of total applied after accounting for N extracted by untreated plants as follows: NEE = 100 × (N_t − N_u)/N_a where NEE = nitrogen extraction efficiency, N_t = nitrogen amount extracted by a treatment that received litter-N plus UAN-N, N_u = nitrogen amount extracted by the treatment that received no litter or UAN, and N_a = amount of total N applied in litter plus UAN.

Litter and supplemental N effects on N uptake were tested using MIXED model analysis on SAS (Littell et al., 2002). Preliminary analysis of variance was performed for a randomized complete block design with a factorial treatment structure for litter and UAN-N factors. Additional analysis was performed using a trend to describe the litter and UAN-N treatment structure as a response surface model where the full model had three slope parameters that included litter linear (L_L) and UAN-N linear (N_L) effects and their interactions ($L_L \times N_L$). The significance of L_L and N_L were tested by omitting the $L_L \times N_L$ interaction term from the full model when the interaction was not significant. Lack of fit, the term used to describe the treatment effect not explained by the response surface, was identified as a random effect in the analysis. The response surface models were combined over years and locations to test for the interaction of litter and UAN-N treatments with location and year. In this combined analysis, the full model allowed the three slope parameters to be different for each year so that there were nine slope parameters, three for each year. A reduced response surface model was also used by omitting nonsignificant terms for a more robust test of the interactions. This reduced response surface model had two slope parameters (L_L and N_L) with the same N_L slope parameter across the years but separate L_L slopes for each year so that there was a total of four slope parameters for all 3 yr combined. The experimental design for data combined over years is a split plot where main plot treatments were the litter and UAN-N treatment combinations as a response surface and the subplot treatment was year as a repeated measure. Random effects for this analysis included two terms for main plot error: lack of fit and replication × main plot treatment. This split plot analysis was also performed combined across both locations. In this analysis location and location × treatment interactions were fixed effects and the errors were pooled across locations. The relationship between N uptake and tissue N concentration with applied total plant available N (N_{TPA}) was tested by regression analysis. The N_{TPA} was estimated by summing litter-N and UAN-N assuming 50% of the total litter N and 100% of the UAN-N become plant available during the cotton growing season. Differences mentioned in the discussion are significant at $P \leq 0.05$ unless stated otherwise.

RESULTS

The two locations were selected to represent a conventional and a no-till cotton production system. In addition to differences in tillage, cultivars, and other management methods, these locations represent two contrasting litter application methods. While applied litter at Cruger was thoroughly incorporated with the soil within 1 d of application, the litter at Coffeeville was left on the soil surface without incorporation. Analysis of end-of-season N concentration and total N uptake data using both the full and reduced response surface models confirmed that the locations were significantly different for most of the litter and UAN-N response surface trends. The results are therefore presented separately by location.

Analysis of N extraction and tissue N concentration data, after combining for the 3 yr within a location, showed that the litter and UAN-N response surface trends were also not the same over the 3 yr, probably because of cumulative residual effect of the treatments which were not assigned to a new random set of plots each year. A plot received the same treatment each of the 3 yr within a location. As a result, the data were analyzed and are presented separately by year within a location.

Nitrogen Concentration in Plant Parts

Cruger

Nitrogen concentration in bulk leaves averaged across all 10 treatments gradually decreased during the growing season (Table 1). Leaf N concentration decreased 37% (from 45.2 g kg^{-1} 68 DAP to 28.5 g kg^{-1} 130 DAP) in 2002 and 29% (from 34.3 g kg^{-1} 78 DAP to 24.5 g kg^{-1} 135 DAP) in 2003. Bulk leaf N concentration in all treatments in the first two sampling days (68 and 97 DAP) in 2002 exceeded 30 g kg^{-1}. The established sufficiency range based on the youngest fully mature leaf blades taken between early and late flowering is 30 to 45 g kg^{-1} (Mitchell and Baker, 2000). Leaf N concentration of all treatments except L_0N_0 and $L_{4.5}N_0$ also exceeded 30 g kg^{-1} on the first sampling (78 DAP) in 2003. Leaf N concentration began to fall below 30 g kg^{-1} in treatments that received the lower litter rates with or without 34 kg ha^{-1} UAN-N starting on the third sampling day (112 DAP) in 2002 and on the second sampling day (98 DAP) in 2003.

Nitrogen concentration in stems and reproductive parts also decreased during the season. Stem N concentration averaged across the 10 treatments decreased by 55% in 2002 and 18% in 2003. Reproductive N concentration decreased by 54% in 2002 and 44% in 2003. While the decrease in stem N concentration may be largely due to remobilization of N to developing bolls, the decrease of N concentration in reproductive parts most likely is because of rapid dry weight accumulation in lint that contains very little N. Lint N concentration at maturity (130 DAP) in 2002 ranged between 1.5 and 2.3 g N kg^{-1} (data not shown). Fritschi et al. (2004) reported slightly greater (2.3 to 3.1 g N kg^{-1}) lint N concentration of mature Acala cotton in California. Nitrogen concentration in burs decreased while that in seed increased during the last two or three measurements. The increase of N concentration in seed, while it decreased in burs and leaves, indicates the common understanding of N remobilization from leaves and fruit walls to seed during the boll growth and maturation period.

Within each sampling day, both applied litter and UAN-N significantly affected N concentration in plant parts measured during the first three sampling days in 2002 and in 2003 (Table 1). Nitrogen concentration in plant parts increased linearly with increasing litter rate or UAN-N rate. On the last sampling, litter and UAN-N did not always significantly affect N concentration in plant parts. The interaction between the linear effect of litter (L_L) and the linear effect of UAN-N (N_L) was not significant on any of the sampling days, which indicates the change in N concentration (slope) with increasing litter rate was the same at any level of the supplemental UAN-N rates. Among all measurements, the STD and $L_{4.5}N_{67}$ treatments had the largest N concentration in the different plant parts. These two treatments were also consistently among the best yielding treatments (Tewolde et al., 2007). The $L_{6.7}N_{34}$ treatment was also among the treatments that had the largest N concentration in plant parts.

Nitrogen concentration of plant parts was significantly associated with applied total plant available N (N_{TPA}) (Table 2, Fig. 1). The association was usually linear with a few significant quadratic relationships. Nitrogen concentration in leaves, stems, and reproductive parts increased with increasing N_{TPA}. Seed N concentration increased linearly with increasing N_{TPA} when it was measured 98 and 121 DAP in 2003. Seed N concentration measured on the last day of measurement (135 DAP in 2003 and 134 DAP in 2004) also increased with increasing N_{TPA} but the increase was nonlinear with a tendency to level off at the largest N_{TPA}. Bur N concentration also increased with increasing N_{TPA}. Lint N concentration which was measured only in 2002 was not related with N_{TPA} when measured before maturity (data not shown). At maturity on the last sampling day, however, lint N concentration had a small linear increase with increasing N_{TPA} (Lint N in g kg^{-1} = 0.0068 × N_{TPA} in kg ha^{-1} + 1.4247, r^2 = 0.87, n = 10).

Coffeeville

Nitrogen concentration in bulk leaves, stems, and reproductive parts at Coffeeville also gradually decreased during the growing season in 2002 (Table 1). It decreased 34% from an average of 38.1 g kg^{-1} 50 DAP to 25.0 g kg^{-1} 112 DAP. Leaf N concentration in all treatments in the first sampling day (50 DAP) exceeded 30 g kg^{-1}. Leaf N concentration of treatments that received ≤4.5 Mg ha^{-1} litter with no supplemental UAN-N began to fall below 30 g kg^{-1} on the second sampling day (71 DAP). Only the $L_{4.5}N_{67}$ treatment maintained leaf N above 30 g kg^{-1} on the third sampling day. Stem N concentration decreased by 50.4% from an average across treatments of 11.7 g kg^{-1} 50 DAP to 5.8 g kg^{-1} 112 DAP. Reproductive N concentration decreased by 40.3% from 36.0 g kg^{-1} 50 DAP to 21.5 g kg^{-1} 112 DAP. Bur N concentration decreased while seed N concentration sharply increased during the last two measurements.

Litter at Coffeeville had a significant (P < 0.10) linearly increasing effect on leaf and stem N concentration in the first three sampling days but had no effect on seed or bur N concentration on any of the sampling days (Table 1). Nitrogen as UAN significantly affected N concentration in leaves, stems, and burs in most of the sampling days but did not affect seed N. Nitrogen concentration of plant parts usually was significantly associated (mostly linearly) with N_{TPA} (Table 2, Fig. 1). Nitrogen concentration in

Table 1. Nitrogen concentration in aboveground plant parts of cotton fertilized with broiler litter plus supplemental N as urea–ammonium nitrate solution (UAN) at Cruger and Coffeeville, MS.

		N concentration																	
		Leaf				Stem				Reproductive parts				Bur			Seed		
UAN-N	Broiler litter	Day1†	Day2	Day3	Day4	Day1	Day2	Day3	Day4	Day1	Day2	Day3	Day4	Day2	Day3	Day4	Day2	Day3	Day4
kg ha^{-1}	Mg ha^{-1}	g kg^{-1}																	
Cruger, 2002																			
0	0	40.9	32.1	22.6	22.7	12.4	8.0	5.2	5.2	38.9	20.3	14.7	17.0	–	11.2	6.9	–	32.6	38.9
	2.2	45.1	32.6	27.5	27.5	14.3	8.4	6.2	6.8	39.7	23.3	16.7	18.3	–	14.2	10.8	–	34.1	39.4
	4.5	45.2	35.1	28.5	25.5	15.7	7.6	6.5	5.7	40.4	21.9	15.2	17.8	–	12.0	8.5	–	34.6	39.2
	6.7	46.0	38.5	30.6	30.0	15.8	10.0	7.4	7.3	40.7	28.7	17.5	18.7	–	15.6	10.5	–	34.4	39.9
34	2.2	46.1	37.9	29.2	23.8	16.3	8.9	6.2	5.3	40.7	26.6	16.8	17.2	–	13.6	7.9	–	34.6	38.1
	4.5	45.1	38.9	32.3	29.9	15.6	9.9	6.8	6.4	39.9	26.1	18.0	19.1	–	15.7	11.5	–	36.3	40.2
	6.7	46.2	37.6	33.8	31.6	16.3	8.3	7.4	7.5	41.1	24.4	19.6	18.9	–	19.4	12.1	–	34.0	39.2
67	2.2	45.3	39.3	31.8	28.6	15.6	10.2	7.3	6.7	40.5	24.7	19.1	19.9	–	17.8	10.8	–	35.6	43.2
	4.5	47.4	42.1	35.1	31.7	15.8	11.2	7.6	7.7	40.4	26.6	19.7	19.0	–	18.2	12.2	–	37.6	39.5
STD‡	0	44.9	41.6	34.8	33.8	14.6	10.5	8.5	8.8	38.7	25.2	20.5	19.2	–	19.8	13.3	–	35.4	38.9
Avg.		45.2	37.6	30.6	28.5	15.2	9.3	6.9	6.8	40.1	24.8	17.8	18.5		15.8	10.5		34.9	39.7
P > F	L_L§	0.006	0.017	<0.001	0.023	0.003	0.070	0.008	0.175	0.004	0.004	<0.001	0.071		0.002	0.044		0.113	0.865
	N_L	0.040	<0.001	<0.001	0.004	0.075	0.162	<0.001	0.014	0.883	0.460	<0.001	0.007		<0.001	0.007		0.023	0.699
Cruger, 2003																			
0	0	20.9	16.5	17.1	21.4	5.4	4.1	4.6	5.9	22.0	11.7	13.4	14.2	11.7	4.9	4.3	21.3	32.4	34.1
	2.2	30.1	23.8	17.2	21.1	7.7	5.5	4.7	5.9	27.4	15.2	14.3	14.3	15.2	6.1	5.0	23.2	34.1	32.9
	4.5	29.4	24.1	18.9	20.6	7.6	5.6	4.9	6.8	27.6	14.3	14.3	14.8	14.3	6.8	6.5	25.2	33.1	33.2
	6.7	36.0	31.5	21.8	24.2	9.9	6.7	5.4	6.8	32.0	22.0	15.3	16.6	22.0	9.0	7.1	24.9	34.1	36.4
34	2.2	35.2	27.7	22.4	22.8	8.3	5.7	4.9	6.5	29.6	17.2	15.9	15.8	17.2	9.7	6.9	26.4	35.0	34.8
	4.5	36.9	30.8	23.4	28.4	10.8	7.0	5.2	8.6	31.7	19.8	16.8	18.0	19.8	11.4	11.4	25.8	36.8	37.6
	6.7	41.3	35.2	27.2	27.3	11.8	7.9	6.0	8.7	33.6	22.7	18.0	18.3	22.7	12.9	9.3	24.9	37.7	38.7
67	2.2	35.8	33.1	22.7	24.2	8.7	6.9	4.7	7.2	30.9	21.0	17.2	17.7	21.0	10.0	7.7	25.9	37.8	38.4
	4.5	39.7	36.2	26.4	26.1	9.8	8.3	6.1	7.8	31.5	22.0	18.7	19.1	22.0	14.6	11.1	27.7	38.4	39.0
STD	0	37.6	38.8	33.5	29.0	9.9	10.2	8.2	9.8	32.3	26.5	20.8	19.9	26.5	18.3	11.5	27.4	39.7	40.8
Avg.		34.3	29.8	23.1	24.5	9.0	6.8	5.5	7.4	29.9	19.2	16.5	16.9	19.2	10.4	8.1	25.3	35.9	36.6
P > F	L_L	<0.001	<0.001	0.013	0.041	<0.001	<0.001	0.303	0.056	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	0.009	0.066	0.029	0.026
	N_L	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	0.005	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001
Coffeeville, 2002																			
0	0	32.6	27.0	25.4	26.6	9.4	5.3	4.9	6.3	32.8	22.5	15.4	21.5	–	14.8	9.9	–	26.4	45.2
	2.2	33.1	26.9	24.1	23.3	10.2	5.7	4.6	5.4	33.0	24.0	16.5	20.3	–	14.3	9.7	–	31.3	42.5
	4.5	36.8	29.8	25.2	25.0	10.0	5.8	4.9	5.6	33.8	23.4	15.2	20.0	–	14.5	8.5	–	26.5	42.0
	6.7	35.5	33.0	26.4	25.5	11.2	5.7	5.0	6.3	34.8	23.9	16.1	20.5	–	14.6	11.1	–	28.7	40.8
34	2.2	39.9	32.1	25.0	24.3	12.4	6.0	4.9	5.8	38.3	24.5	16.4	21.4	–	15.0	9.9	–	27.9	44.4
	4.5	36.4	31.9	25.5	25.2	11.3	6.2	4.9	6.0	35.9	24.8	16.4	21.6	–	15.2	11.1	–	28.4	44.1
	6.7	41.3	33.2	27.7	24.7	12.5	6.8	5.4	5.5	37.3	24.7	16.5	22.4	–	16.6	10.0	–	26.0	46.1
67	2.2	43.0	34.4	26.3	23.4	13.5	6.8	5.0	5.3	38.2	26.5	15.7	21.7	–	16.1	10.4	–	23.5	44.3
	4.5	41.8	37.0	31.9	26.0	14.0	7.8	6.5	6.0	39.0	26.5	18.2	23.2	–	19.1	11.5	–	26.4	46.4
STD	0	40.9	38.1	28.0	25.7	11.9	8.0	5.9	5.6	37.2	28.8	17.2	22.5	–	17.6	11.3	–	26.3	45.7
Avg.		38.1	32.3	26.6	25.0	11.7	6.4	5.2	5.8	36.0	25.0	16.4	21.5		15.8	10.3		27.1	44.2
P > F	L_L	0.068	0.020	0.087	0.990	0.068	0.087	0.212	0.915	0.114	0.554	0.246	0.671		0.222	0.377		0.912	0.635
	N_L	0.003	<0.001	0.026	0.856	0.006	<0.001	0.018	0.478	0.005	<0.001	0.030	0.016		0.004	0.055		0.227	0.105

† Day1, Day2, Day3, and Day4, respectively, refer to the first, second, third, and fourth date of sampling as described under materials and methods.

‡ STD, farm standard fertilization.

§ L_L, linear effect of litter; N_L, linear effect of UAN-N.

leaves, stems, and reproductive parts during the first three sampling days increased with increasing N_{TPA}.

End-of-Season Nitrogen Extraction

Cruger

The L_0N_0 treatment, that received no litter or UAN-N, extracted 125 kg N ha^{-1} in 2002 and 91 kg N ha^{-1} each in 2003 and 2004 (Fig. 2). Applying litter with or without supplemental UAN-N increased the amount of extracted total N in direct proportion to the litter rate with no significant $L_L \times N_L$ interaction (Table 3; Fig. 2). The $L_{4.5}N_{67}$ treatment, which consistently yielded as good as or better than the STD (Tewolde et al., 2007), was among the treatments that had the largest N extraction with 196, 242, and 260 kg N ha^{-1} total extraction in 2002, 2003, and 2004, respectively. These amounts were very similar to the N extraction of the STD with 184, 259, and 278 kg N ha^{-1} in 2002, 2003, and 2004, respectively.

The amount of extracted N at this location exceeded total N applied when averaged across all 10 treatments (Fig. 2 and Table 4). Average applied N as a sum of litter-N and UAN-N was 115, 130, and 165 kg ha^{-1} compared with the corresponding average uptake of 172, 171, and 214 kg ha^{-1} in 2002, 2003, and 2004, respectively. Within each treatment, extracted N equaled or exceeded the total applied each of the 3 yr with the exception of the $L_{6.7}N_0$ treatment which extracted 14 and 26 kg ha^{-1} less N than applied in 2003 and 2004, respectively.

The entire amount of N extracted by plants is not supplied by applied fertilizers. Some fraction of it is supplied by the soil N reserve, the simplest measure of which may be the amount extracted by unfertilized plants. When averaged across all treatments, NEE calculated after accounting for N extracted by untreated plants was 42, 61, and 71% in 2002, 2003, and 2004, respectively (Table 4). Supplementing litter with UAN-N usually improved NEE relative to nonsupplemented litter, which was particularly true with 4.5 and 6.7 Mg ha^{-1} litter rates. For example, in 2003, the NEE of the treatment that received 4.5 Mg ha^{-1} litter was 25% without supplemental UAN-N but increased to 53% when supplemented with 34 kg ha^{-1} UAN-N and to 83% when supplemented with 67 kg ha^{-1} UAN-N.

Coffeeville

The L_0N_0 treatment at this location extracted 107 kg N ha^{-1} in 2002 and 100 kg N ha^{-1} each in 2003 and 2004 (Fig. 2). These amounts may be considered the N supplying capacity of the soil at Coffeeville. Applying litter increased the amount of extracted total N in direct proportion to the litter rate with no significant $L_L \times N_L$ interaction (Table 3; Fig. 2). The $L_{4.5}N_{67}$ and $L_{6.7}N_{34}$ treatments, which were among the best yielding treatments at this location (Tewolde et al., 2007), extracted more N than any other treatment. The $L_{4.5}N_{67}$ treatment extracted 199, 165, and 186 kg N ha^{-1} and the $L_{6.7}N_{34}$ treatment extracted 199, 175, and 161 kg N ha^{-1} in 2002, 2003, and 2004, respectively. The corresponding extraction by the STD was 198, 123, and 168 kg N ha^{-1}.

Plants at Coffeeville, unlike plants at Cruger, usually extracted less N than the total amount applied (Fig. 2 and Table 4). When averaged across the 10 treatments, extracted N at Coffeeville was only slightly more or less than applied N each of the 3 yr. Average applied total N was 150, 145, and 153 kg ha^{-1} compared with average

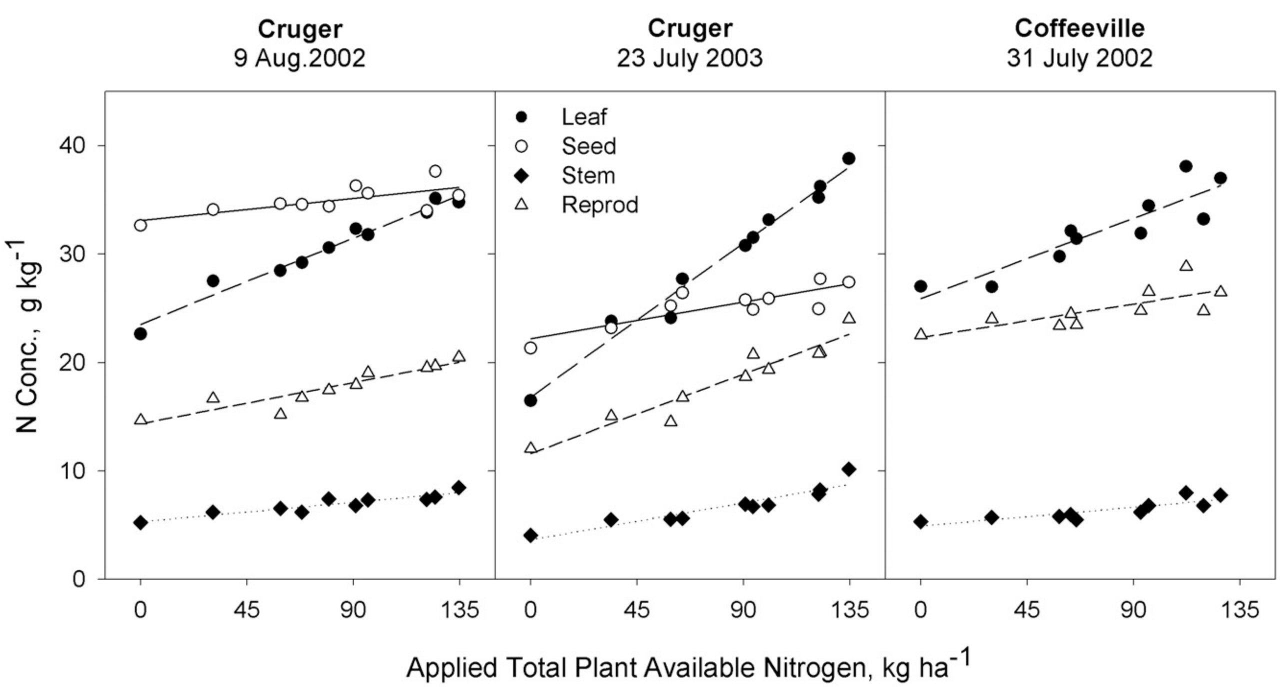

Figure 1. Relationship between applied total plant available N (N_{TPA}) and N concentration in plant parts of cotton grown with broiler litter plus supplemental N as urea–ammonium nitrate solution at Cruger and Coffeeville, MS, on selected dates in 2002 and 2003.

extracted N of 161, 131, and 140 kg ha^{-1} in 2002, 2003, and 2004, respectively. But, treatments differed in the amount of extracted N relative to the applied. Extracted N exceeded or nearly equaled applied N when only 2.2 Mg ha^{-1} litter was applied regardless of the amount of supplemental N. When applied litter was 6.7 Mg ha^{-1}, however, extracted N was less than applied regardless of the level of supplemental UAN-N. The largest discrepancy between extracted and applied N under this treatment was 79 kg N ha^{-1} in 2002, 97 kg N ha^{-1} in 2003, and 79 kg N ha^{-1} in 2004 when no supplemental N was applied. The treatment that received 4.5 Mg ha^{-1} litter also extracted less N than applied regardless of the amount of supplemental UAN-N. The $L_{4.5}N_{67}$ treatment, which was also the best yielding treatment (Tewolde et al., 2007), extracted 24, 61, and 41 kg ha^{-1} less N than applied in 2002, 2003, and 2004, respectively. The STD, which received UAN-N by injection into the soil, extracted 86, 5, and 50 kg ha^{-1} more N than applied in 2002, 2003, and 2004, respectively, but yielded less than the $L_{4.5}N_{67}$ treatment.

Nitrogen extraction efficiency averaged across all treatments at Coffeeville was 39, 22, and 24% in 2002, 2003, and 2004, respectively (Table 4). The tendency of NEE to increase with increasing supplemented UAN-N observed at Cruger was also observed at Coffeeville. Nitrogen extraction efficiency at this location significantly and linearly increased with increasing UAN-N rate in 2002 and 2004.

Partitioning of Nitrogen to Plant Parts

Nitrogen extracted by aboveground plant parts a few days before defoliation was partitioned largely to the boll. Nearly 69% of the N at this stage was recovered in seed, lint, and burs. When averaged across all treatments, years, and locations, ≈57% of the total N accumulated in aboveground plant parts was recovered in the seed alone and an additional 2.4% in lint. The sum of these values (59.4%) represents the proportion of extracted N that would be removed from the field. Plants partitioned an average across treatments of 62% of the total extracted N to seed and lint at Coffeeville and 56% at Cruger.

Partitioning of dry weight to seed was only 25% at both locations when averaged across all treatments and years (data not shown). Dry weight partitioning to lint was an average of 18% at Cruger and 22% at Coffeeville compared with a corresponding N partitioning to lint of only 2.3% and 2.6%, respectively. The average N accumulation in lint did not exceed 3 to 6 kg N ha^{-1} under either location and in any of the 3 yr.

Nitrogen partitioned to stems was five to six times less than N partitioned to seed (Fig. 2), while dry weight partitioned to stems at both locations was comparable to dry weight partitioned to seed (data not shown). The overall average dry weight partitioned to stem was the same as that partitioned to seed which was ≈25%. But, while the average N partitioned to seed was ≈57% of the total, the average N partitioned to stem was only ≈10%.

Table 2. Coefficient of determination (r^2) values from regressing N concentration (n = 10) in cotton plant parts on total plant available N (N_{TPA}) applied as broiler litter plus supplement urea-ammonium nitrate solution.

Location	Date	Plant Part: Leaf	Stem	Reproductive	Bur	Seed
		r^2				
Cruger	26 June 2002	0.74†	0.87†	0.52†	–	–
	25 July 2002	0.83	0.47	0.37	–	–
	9 Aug. 2002	0.97	0.86	0.86	0.83	0.49
	27 Aug. 2002	0.75	0.61	0.57	0.68	ns
	3 July 2003	0.86	0.76	0.94†	–	–
	23 July 2003	0.98	0.93†	0.92	0.91	0.70
	15 Aug. 2003	0.89†	0.77†	0.91†	0.90†	0.78
	29 Aug. 2003	0.68	0.70	0.94†	0.75	0.91†
	31 Aug. 2004	0.66	0.67	0.92†	0.70	0.95†
Coffeeville	10 July 2002	0.66	0.66	0.53	–	–
	31 July 2002	0.81	0.72	0.56	–	–
	22 Aug. 2002	0.83†	0.75†	0.42	0.88†	ns
	10 Sept. 2002	ns‡	ns	0.84†	0.32	0.72†
	16 Sept. 2003	0.56	0.71	0.68†	ns	0.73†
	13 Sept. 2004	ns	0.52†	ns	ns	0.38

† r^2 values for quadratic fit; all other r^2 values are for linear fit. ns, fitted linear or quadratic model not significant at $P < 0.10$; all other fitted models significant at $P < 0.10$.

‡ ns, not significant.

Partitioning of N to leaves and burs was more comparable with partitioning of dry weight to these plant parts. Average N partitioned to leaves was 21% compared with average dry weight partitioned to leaves of 12% (data not shown). Average N partitioned to burs was 10% compared with 15% dry weight partitioned to burs. The proportion of N partitioned to leaves was low primarily because the measurements were made late in the season, within a few days before defoliation. At earlier growth stages around the flowering stage, leaves make up a large fraction of the aboveground plant dry weight and become great N sinks. But, as bolls start to form and expand, a large amount of the leaf N is remobilized to developing seeds. This is followed by drastic decrease in N concentration in these leaves (Table 1) and by self-defoliation of the older leaves.

Litter or UAN-N application did not usually significantly affect N partitioning measured as plants approached maturity. When there was a significant treatment effect, the effect in one season or location did not hold the same trend in another season or location.

DISCUSSION

Nitrogen concentration of bulk leaves (petioles + blades of all leaves) was measured to determine total N uptake but also to evaluate how bulk leaf N concentration compares against established sufficiency range, which is based

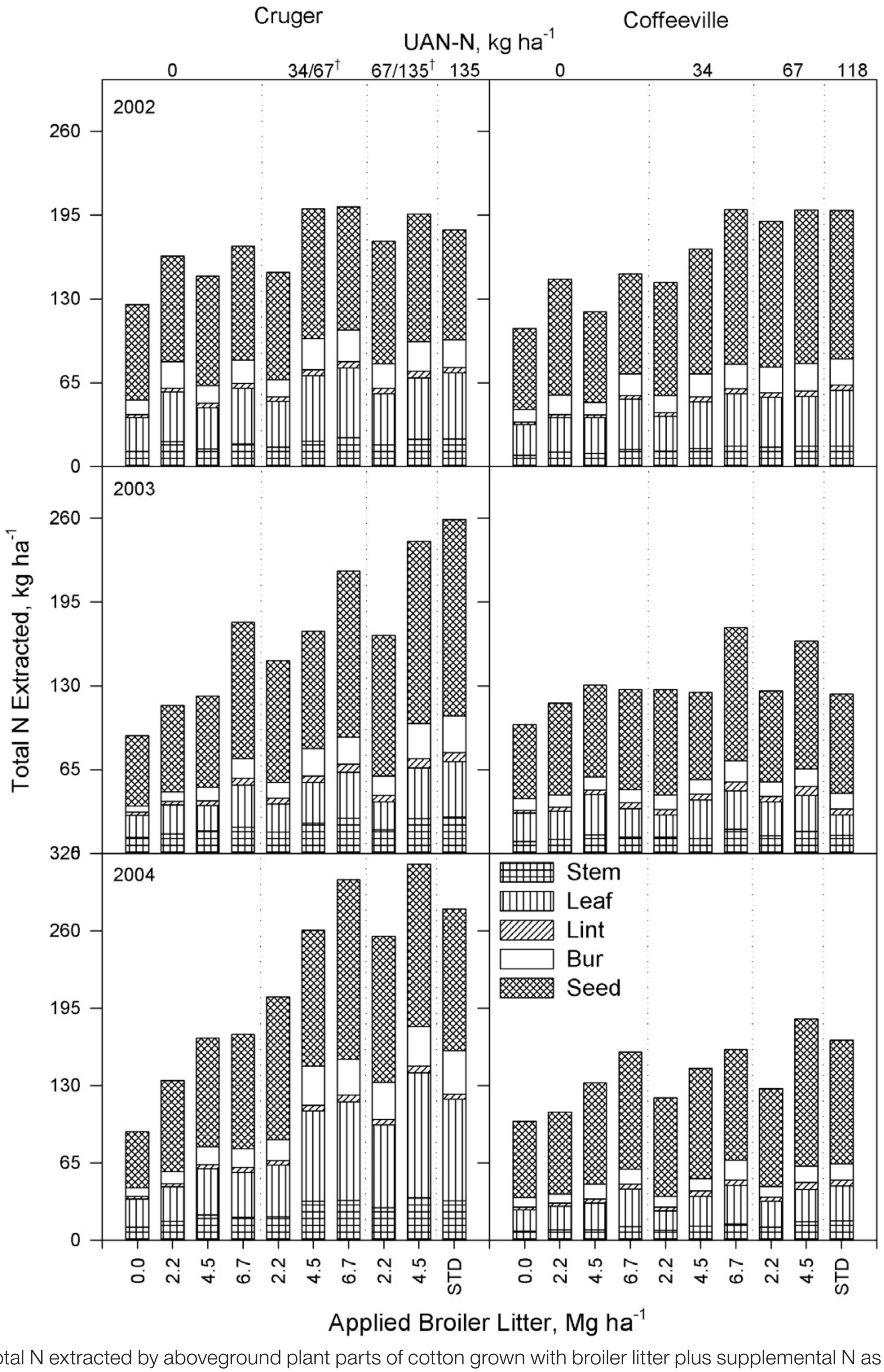

Figure 2. Total N extracted by aboveground plant parts of cotton grown with broiler litter plus supplemental N as urea–ammonium nitrate (UAN) solution at Cruger and Coffeeville, MS, during 2002 to 2004. † Applied UAN-N rates in 2004 at Cruger were 67 and 135 kg ha^{-1} instead of the 34 and 67 kg ha^{-1} applied in 2002 and 2003. STD = farm standard fertilization.

on the youngest mature leaf blade. Bulk leaf N concentration of all treatments around the early flowering and early boll development stages at both Cruger and Coffeeville fell within the 30 to 45 g N kg^{-1} established sufficiency range (Mitchell and Baker, 2000). This was not expected because we measured leaf N on all whole leaves (blade + petioles) while the published sufficiency range was based on the youngest fully mature leaf blade taken

Table 3. Statistical significance ($P > F$) of the linear effect of applied broiler litter (L_L) or N as urea–ammonium nitrate solution (N_L) on end-of-season N uptake by aboveground parts of cotton grown at Cruger and Coffeeville, MS (data shown in Fig. 2). Only the linear effects are shown as the interaction between $L_L \times N_L$ were not significant at $P < 0.05$.

Location	Season	Effect	Plant part					
			Leaf	Stem	Bur	Lint	Seed	Total
			$P > F$					
Cruger	2002	L_L	0.007	0.007	0.024	0.002	0.007	0.004
		N_L	0.003	0.002	0.028	0.002	0.036	0.004
	2003	L_L	0.019	<0.001	<0.001	<0.001	<0.001	<0.001
		N_L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
	2004	L_L	0.027	0.017	0.040	<0.001	0.001	<0.001
		N_L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Coffeeville	2002	L_L	0.006	0.007	0.017	<0.001	0.080	0.016
		N_L	<0.001	<0.001	<0.001	<0.001	0.002	<0.001
	2003	L_L	0.095	<0.002	0.011	<0.001	0.015	<0.001
		N_L	0.796	0.004	0.012	0.002	0.058	0.025
	2004	L_L	0.046	0.015	0.064	0.003	0.058	0.025
		N_L	0.156	<0.001	0.098	<0.001	0.023	0.011

between early and late flowering. We expected the bulk leaf N concentration of some of the treatments—at least that of the unfertilized control (L_0N_0)—in our research to fall below the sufficiency range because all leaves including old and senescent leaves were sampled. However, the results may be an indication that either the established sufficiency range is too inclusive or our expectation—that the bulk leaf N concentration should be less than the sufficiency range—is unrealistic on these sampling days. Critical levels reported by Bell et al. (2003) suggest 30 g N kg^{-1} as the lowest boundary in the established sufficiency range of 30 to 45 g N kg^{-1} may be too low. Bell et al. (2003) established that N concentration in the uppermost fully mature leaf blade associated with yield loss was 43 g kg^{-1} at early flowering and 41 g kg^{-1} 3 wk after early flowering in research conducted at seven locations in Mississippi, Louisiana, Arkansas, and Alabama. Bulk leaf N concentration of some inadequately fertilized treatments in our research were still equal or greater than these critical values reported by Bell et al. (2003), which suggests the issue of which leaf or leaves to sample and whether the 30 to 45 g kg^{-1} sufficiency range is accurate should be revisited and evaluated regardless of whether the cotton is fertilized with manure or conventional inorganic fertilizers.

Loss of litter-derived inorganic and organic N to the immediate environment due to inefficient extraction is a concern when poultry litter is used as a primary row crop fertilizer. When fertilized with inorganic fertilizers, the largest total N uptake reported in past research is 224 to 235 kg N ha^{-1} (Halevy, 1976). If poultry litter is applied to meet 100% of the N requirement of cotton, it may be necessary to apply as much as 9.0 Mg litter ha^{-1} (Tewolde et al., 2007) which may supply as much as 250 to 300 kg total N ha^{-1}. In our research, cotton fertilized with as much as 4.5 or 6.7 Mg ha^{-1} litter supplemented with 67 or 34 kg ha^{-1} UAN-N extracted as much as 316 kg N ha^{-1} which exceeded total applied N (Fig. 2; Table 4).

However, not the entire extracted N is removed from the field in harvested crop. On average, only ≈59% of extracted N is removed from the field in harvested seed and lint. The most consistently best yielding treatment ($L_{4.5}N_{67}$) removed an average across years of 124 kg N ha^{-1} (53% of total uptake) at Cruger and 119 kg N ha^{-1} (65% of total uptake) at Coffeeville with harvested seed and lint. Fritschi et al. (2004) reported similar N partitioning to seed and lint (an average of 59.1%) in Acala cotton grown in California with inorganic fertilizers. A much earlier research also in California with Acala cotton reported 44 to 58% N partitioning to seed and lint (Bassett et al., 1970). Others, however, reported much lower (42–49%) N partitioning to seed and lint (Halevy, 1976; Mullins and Burmester, 1990).

Up to 47% of the total extracted N at Cruger and up to 35% at Coffeeville was bound in aboveground plant parts that remained in the field after harvest. This amount does not include N extracted during the season and lost in abscised leaves and reproductive parts that can be as much as 26% of the total (Boquet and Breitenbeck, 2000). An additional undetermined amount is also bound in root tissues that can be as much as 14% at the early boll development stage in container-grown plants (Tewolde et al., unpublished data, 2004). Although the N fraction bound in roots, stems, leaves, and burs is not removed from the field, it has little or no risk of becoming released to the immediate environment until the plant parts decompose and organic N mineralizes. This shows the risk of litter-derived N detrimentally affecting the immediate environment when fertilizing cotton with litter supplemented with inorganic N fertilizers is no greater than when fertilizing with 100% inorganic N fertilizers.

Table 4. Total amount of N applied in broiler litter plus urea–ammonium nitrate solution (UAN) and efficiency of cotton in extracting applied N at Cruger and Coffeeville, MS, at the end of the season in 2002 to 2004. Litter-supplied N was determined as a product of total N concentration in litter and actual amount of applied litter.

UAN-N†	Broiler litter	Cruger 2002	Cruger 2003	Cruger 2004	Cruger Avg.	Coffeeville 2002	Coffeeville 2003	Coffeeville 2004	Coffeeville Avg.
kg ha^{-1}	Mg ha^{-1}	Total N applied, kg ha^{-1}							
0	0	0	0	0	0	0	0	0	0
	2.2	55	70	62	62	79	65	76	73
	4.5	106	122	145	124	154	149	157	153
	6.7	142	193	208	181	229	224	236	230
34 (67)	2.2	95	96	136	109	112	105	108	108
	4.5	136	151	212	166	189	189	197	192
	6.7	190	214	269	224	259	246	265	257
67 (135)	2.2	119	136	202	152	143	131	144	139
	4.5	170	181	279	210	223	225	227	225
STD	0	135	135	135	135	112	118	118	116
Avg.		115	130	165	136	150	145	153	149
		N extraction efficiency, %							
0	0	–	–	–	–	–	–	–	–
	2.2	73.1	33.7	71.8	59.5	49.3	26.0	5.4	26.9
	4.5	20.7	25.2	52.4	32.8	8.4	20.3	19.6	16.1
	6.7	33.6	46.1	39.5	39.8	15.0	11.8	23.2	16.7
34 (67)	2.2	25.0	61.5	83.3	56.6	31.9	26.3	15.2	24.5
	4.5	54.6	53.4	80.5	62.9	32.9	11.5	20.9	21.8
	6.7	40.2	59.4	78.8	59.5	35.8	30.0	21.5	29.1
67 (135)	2.2	41.8	57.7	81.1	60.2	58.2	19.8	16.4	31.5
	4.5	41.8	83.2	78.3	67.8	41.1	28.1	35.8	35.0
STD	0	43.2	124.7	138.9	102.3	81.4	20.0	55.1	52.2
Avg.		41.6	60.5	78.3	60.1	39.3	21.5	23.7	28.2
$P > F$	L_L‡	0.833	0.520	0.118	–	0.085	0.368	0.326	–
	N_L	0.991	<0.001	0.114	–	0.047	0.484	0.010	–

†Applied UAN-N rates in 2004 at Cruger were 67 and 135 kg ha^{-1} (as shown in parenthesis) instead of the 34 and 67 kg ha^{-1} used in 2002 and 2003. STD, farm standard fertilization; UAN, urea–ammonium nitrate solution.

‡L_L, linear effect of litter; N_L, linear effect of UAN-N.

Unlike cotton in our research, which extracted more total N than applied at least at Cruger, certain forage and pasture grasses appear to extract much less litter-N than applied. For example, Evers (2002) reported a maximum annual N uptake of 285 kg ha^{-1} by a ryegrass–bermudagrass pasture that was fertilized with 565 kg ha^{-1} total N (341 kg ha^{-1} broiler litter-N plus 224 kg ha^{-1} N from NH_4NO_3) applied four times during the year. When litter was the only source of applied N, the N uptake was only 84 kg ha^{-1} by ryegrass and 69 kg ha^{-1} by bermudagrass for a total of 154 kg ha^{-1} annual N uptake, which represented only 45% of the total litter-supplied N. Brink et al. (2004) reported total N uptake of 316 kg ha^{-1} (averaged across seven cultivars and 4 yr) on an annual basis, which represented only 58% of the total applied broiler litter-N. In pot experiments, Chadwick et al. (2000) estimated the total uptake of organic litter-N by perennial ryegrass to range between 16 and 56% of the initial. They reported even less uptake of organic N derived from dairy and pig slurries. These results suggest cotton may be a more effective crop than, or at least as effective as, forage and pasture grasses—which are harvested several times during the year—in extracting and utilizing litter-supplied N. The N extraction efficiency of cotton is related to its capacity to accumulate a large amount of N in its seed, an average across treatments and years of 54% of the total extraction at Cruger and 60% of the total extraction at Coffeeville. Boquet and Breitenbeck (2000) also described cotton as an exceptionally N efficient crop, in part, because they found the amount of N removed from the field in harvested seed and lint was equivalent to the amount of inorganic fertilizer-N applied for optimal yield. Cotton may still extract applied N in excess of the amount necessary for optimal yield, but the excess is accumulated in other plant parts that are not harvested (Boquet and Breitenbeck, 2000).

Cotton appeared less efficient in utilizing litter-derived N at Coffeeville than at Cruger although the differences cannot be tested statistically (Fig. 2 and Table 4). The N extraction efficiency (NEE) of treatments that received litter with or without UAN-N relative to the STD was also generally less at Coffeeville than at Cruger (Table 4). While it appears cotton at Coffeeville was less able to extract litter-N than cotton at Cruger, the results may simply be a reflection that, before the litter-N becomes available for uptake, a greater fraction of it is lost at different stages of application at Coffeeville under the no-till than at Cruger under the conventional-till. The litter at both locations was applied by surface broadcasting using a fertilizer spreader. The litter was soil-incorporated within 1 d of application at Cruger but was left on the soil surface with no incorporation throughout each season at Coffeeville because of the no-tillage system at this location. Although unincorporated surface applied litter may be an effective method of fertilizing no-till cotton (Tewolde et al., 2007; Mitchell and Tu, 2005), lack of incorporation at Coffeeville may have increased the vulnerability and loss of mineralized litter-N to runoff or volatilization and reduced the NEE by decreasing the amount of applied litter-N that eventually became available for plant uptake. Depending on the conditions of litter and weather, it is possible to lose as much as 24% of the total litter-supplied N as NH_3 during a season with the greatest loss occurring within the first week of application (Sharpe et al., 2004). Other factors may also have contributed to the smaller NEE at Coffeeville than at Cruger. Because uptake is a function of total growth, conditions that lead to less plant growth are likely factors that may have caused cotton at Coffeeville to be less efficient than cotton at Cruger in extracting litter-supplied N.

Nitrogen extraction efficiency at both locations usually was greater with than without supplemented UAN-N. This was particularly true with the litter rates of 4.5 and 6.7 Mg ha^{-1}. The lower efficiency of N extraction when litter alone was applied than when litter was supplemented with UAN-N may be a reflection of the nature of the litter-N. Approximately 40 to 50% of litter-N is considered to be unavailable for plant uptake in the first season. This should have contributed to the low NEE when litter was not supplemented with UAN-N (all of which is available for plant uptake in the same season), because NEE was determined based on the total N applied.

SUMMARY AND CONCLUSIONS

This research demonstrated that 4.5 Mg ha^{-1} broiler litter supplemented with 67 kg N ha^{-1} from inorganic fertilizers or 6.7 Mg ha^{-1} litter supplemented with 34 kg N ha^{-1} from inorganic fertilizer supplies adequate N nutrition equivalent to that of farm standard fertilization. Midseason N concentration in bulk leaves of the treatment that received 4.5 Mg ha^{-1} litter plus 67 kg ha^{-1} UAN-N, which resulted in the best overall yield, or the treatment that received 6.7 Mg ha^{-1} litter plus 34 kg ha^{-1} UAN-N was comparable to the bulk leaf N concentration of the farm standard treatment. Additionally, plants under these two litter plus UAN-N treatments accumulated as much N as, or more N than, the farm standard treatment suggesting these litter and UAN-N combinations supplied adequate N.

The results also demonstrated plants that received litter and UAN-N combinations that supplied adequate N extracted more N than applied at Cruger and slightly less than applied at Coffeeville. Nitrogen extraction efficiency, sometimes referred to as apparent N recovery, averaged across treatments and years was 28% at Coffeeville and 60% at Cruger. Nitrogen extraction efficiency of the treatments that received 4.5 or 6.7 Mg ha^{-1} litter usually was greater with than without supplemental UAN-N. Approximately 57% of extracted N was partitioned to seed and an additional 2.4% was partitioned to lint, the sum of which represents an amount that would be removed from the field. Cotton partitioned an average across treatments of 62% of the total extracted N to seed and lint at Coffeeville under no-till and 56% at Cruger under conventional-till.

These results demonstrate that cotton extracts N equivalent to the amount that may be supplied by as much litter as 4.5 to 6.7 Mg ha^{-1} when supplemented with inorganic N fertilizers. While only about 59% of this amount is removed from the soil in harvested crop, an amount equivalent to the remainder is bound in plant tissues with little or no risk of becoming released to the immediate environment until the plant parts decompose and organic N mineralizes. Our results show the risk of litter-derived N detrimentally affecting the immediate environment when fertilizing cotton with litter supplemented with inorganic N fertilizers is no greater than when fertilizing with 100% inorganic N fertilizers. When compared with reported N uptake of forage grasses, our results suggest that cotton may be a more ideal crop than, or at least as ideal as, forage and pasture grass crops to which litter can be applied as a fertilizer.

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